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Traffic Service Position System No. 1:

Remote Trunk Arrangement and Position Subsystem No. 2: Transmission and Signaling Considerations

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Transmission and signaling implications are important for the successful introduction of the Remote Trunk Arrangement (RTA) and the Position Subsystem (PSS) No. 2 features into the Traffic Service Position System (TSPS), since both features involve the possibility of substantial distances between the TSPS operators and the customers. Consequently, a new transmission plan including objectives for inserted connection loss (ICL), received noise, balance, and operator sidetone was established and some new transmission equipment was provided. The overall objectives, general and specific considerations, maintenance facilities, signaling implications, and new transmission equipment are described. Emphasis is placed on those aspects that are novel or newly introduced as the result of RTA and PSS No. 2.

I. OVERVIEW

An RTA or PSS No. 2 being located at a remote site several hundred miles distant from the base TSPS presents an entirely new set of transmission and signaling implications. First, there is the peripheral control link or PCL, which extends the control capability of the TSPS processors to the remote locations. Then there are transmission considerations within the RTA and PSS No. 2, modifications required to PSS No. 1, the introduction of new transmission equipment, signaling ramifications, and finally the need for additional impedance balancing.

1.1 The peripheral control link (PCL)

Figure 1 shows the PCL which includes, among other components,

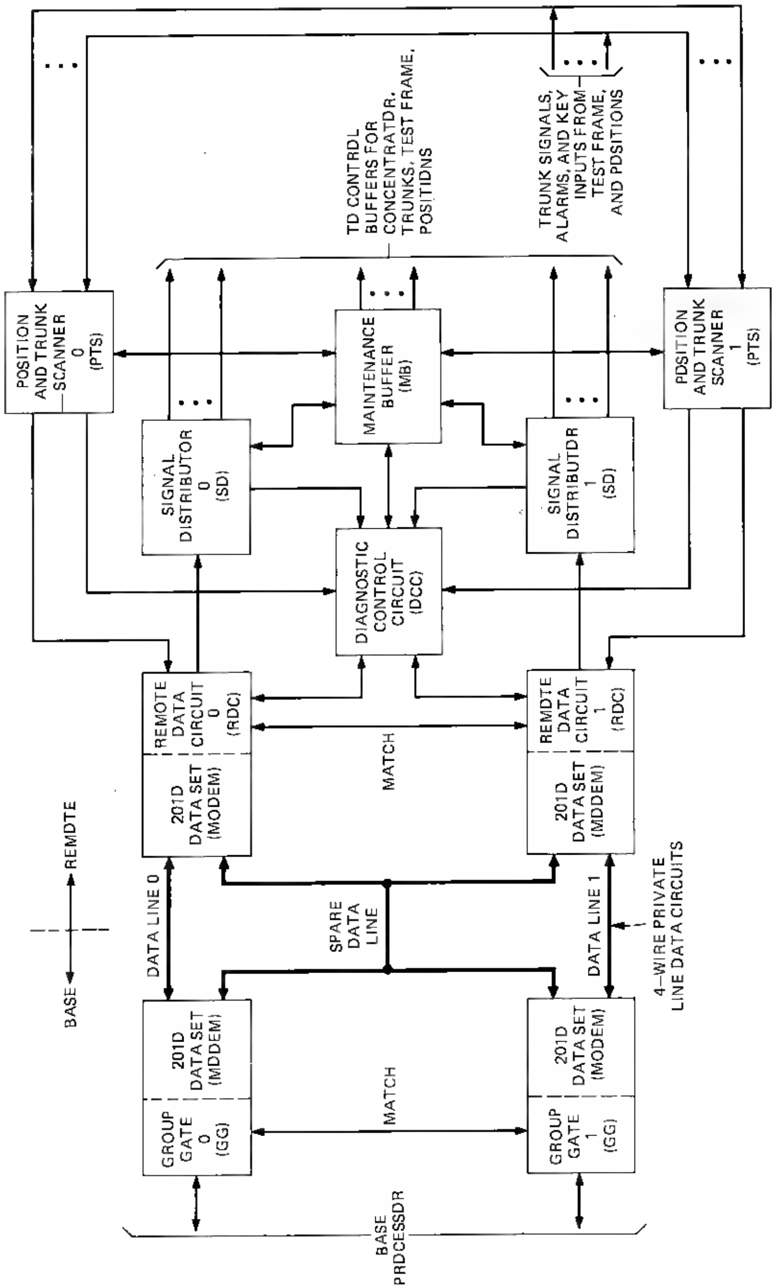

Fig. 1—Peripheral control link.

three data lines used to transmit and receive information to and from the remote sites. System requirements dictate that any standard intertoll grade transmission facilities may be used for all circuits between the base and the RTA or PSS No. 2. Hence, the data transmission circuits must also meet that constraint. Accordingly, the PCL employs 2400 baud modems with the data lines treated as unconditioned, 4-wire private line circuits. This moderate data rate coupled with distances of up to several hundred miles between modems requires that the round-trip delay time required to transmit an instruction to a remote site and receive back an acknowledgment must be limited and must be considered in the design of the data lines.

For reliability, another system requirement specifies that the transmission facilities between base and remote follow at least two diverse routes with one of the two primary data lines in each route. Since, under normal operation, data received on these lines are compared or "matched," a limit must also be placed on the delay differential; that is, on the difference between the delay times of the two routes. Both the delay differential and the round-trip delay times cannot be so restrictive, however, that they substantially restrict the choice of alternate routes between the base and the remote units or severely limit the length of the voice transmission facilities.

1.2 The remote trunk arrangement (RTA)

At the RTA, connection to a TSPS operator is made by bridging onto the toll connecting trunks (TCTS) in a manner similar to that employed at the base. This is shown in Fig. 2. Bridging 900-ohm, 2-wire trunks is accomplished by a simple tap that presents a 450-ohm impedance (two 900-ohm terminations in parallel) to the RTA network (concentrator). Bridging 4-wire trunks requires an associated 3-way, 4-wire bridging repeater which converts the 4-wire bridged tap to 2-wire and which also presents a nominal impedance of 450 ohms to the concentrator. Conversion of 4-wire circuits to 2-wire is always required, since both the RTA and the base TSPS switching networks (RTA concentrator and TSPS trunk and position link circuits) are 2-wire.

The RTA concentrator connects the bridged TCT to a base-remote (BR) trunk, typically a 4-wire intertoll grade facility up to several hundred miles long. Two-wire to 4-wire conversion at both ends of the BR trunk is accomplished by 24V4-type repeaters using a 900-ohm, 4-wire terminating set (4WTS) at the base and a high-impedance 4WTS at the RTA. Finally, the connection is completed through the base network to an operator's position, either a PSS No. 1 or a PSS No. 2.

If the performance of this connection as a function of the length of the BR and operator position trunks is examined, two types of transmission degradation are encountered. The first is echo, as detected by

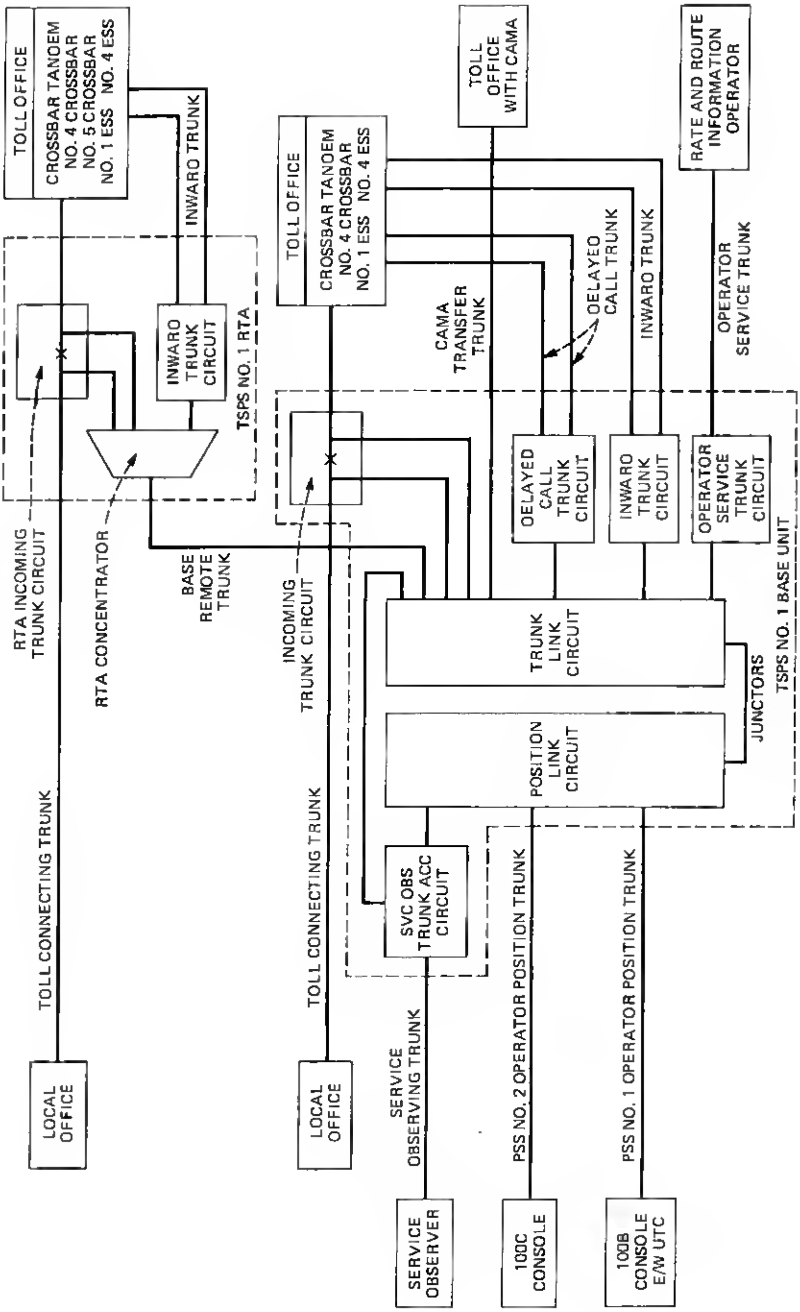

Fig. 2—TSPS No. 1—voice transmission configuration.

the customer(s) and the operator, due to the impedance mismatch at the extra switching point introduced at the RTA concentrator and accentuated by the long BR (and operator position) trunks. As discussed later, echo is controlled through impedance balancing and by a new operator's telephone circuit. The second form of transmission degradation is noise introduced by the long facilities and controlled by the use of compandors on analog facilities or by the use of digital facilities.

1.3 The position subsystem (PSS) No. 2

PSS No. 2 was devised to eliminate the constraints of the original position arrangement (PSS No. 1), which uses unique D1C channel banks and T1 carrier as the transmission facilities for remote installations, and thus is limited in range to approximately 80 miles. Conversely, PSS No. 2 may use any toll grade carrier system and is limited in range only by the noise introduced by the transmission facilities. Hence, received noise is the limiting parameter in the permissible distance between operators and RTAs when standard message grade circuits are used.

The 4-wire operator trunk circuits are connected to the TSPS switching network via 24V4 repeaters and high-impedance 4WTS in the same way as BR trunks at the RTA concentrator. This arrangement permits the PSS No. 2 circuits to be connected to the bridged base TCTs or to BR trunks. At each operator's position, new 4-wire telephone networks provide adjustable sidetone, automatic gain control (AGC), and a voice switched attenuator (VSA).

1.4 The position subsystem (PSS) No. 1

It is necessary and desirable to add RTAs to existing TSPSs which have the original position subsystem arrangements, now designated PSS No. 1. This arrangement employs the equivalent of an unbalanced 4WTS at the base unit end of the position trunks to return a fixed portion of the operator's transmitted signal which serves as sidetone to the operator. No VSA or sidetone adjustment is provided. When an RTA is added, however, the possibility of additional echo from the connection at the RTA makes this an unsuitable arrangement. Hence, the PSS No. 1 unbalanced 4WTS is replaced with a precision balanced 4WTS, and the position is equipped with the same telephone network used in the PSS No. 2. No changes are required in the PSS No. 1 when only PSS No. 2 is added to an existing system.

1.5 Transmission balance

With the introduction of RTA and PSS No. 2, the geographical extent of a single TSPS was transformed from a rather confined area around

a toll office to a system that might cover complete states or even larger areas. Under these circumstances, the distance a call must travel to the operator access point in the network may be significant compared to the length of the average customer-to-customer connection. In those cases, it becomes necessary to treat the operator connection as a toll facility. Toll facilities are characterized by trunks and switching networks which are low loss and transmission balanced and, indeed, these are exactly the requirements that have been introduced into TSPS. Transmission "balance" means matching impedances at all 2-wire to 4-wire junctions to maintain a loss design that allows accurate summation of the losses of the parts while at the same time preventing unwanted signal reflections or "echos" from mismatched junctions.

In the past, balance was not required for TSPS equipped with PSS No. 1 positions, and such systems still do not require balancing. However, whenever a TSPS is equipped with an RTA or is equipped with a PSS No. 2 in which the operator trunks exceed 200 miles in length, the entire system must be balanced.

To facilitate balancing, adjustable network build-out capacitors (NBOCs) are provided by all the 4WTSs or equivalent used in the system. Drop build-out capacitors (DBOCs) are provided or specified at the 2-wire line (or drop) anywhere there is a 4-wire/2-wire transformation on the trunk-link side of the TSPS network.

1.6 Inward trunks

With the introduction of TSPS Generic Program 7, TSPS base units and RTAs have the capability of performing some traditional inward operator functions such as general assistance, time and charges, call-back, and hotel call-back. A special 4-wire inward trunk must be used to handle inward calls. This inward trunk is composed of a toll office outgoing trunk circuit, a TSPS 4-wire bridging arrangement to provide TSPS operator access to the inward trunk, and a toll office incoming trunk circuit. These three circuits are interconnected by 4-wire facilities. An incoming call is switched by the toll office to the outgoing trunk circuit associated with an inward trunk and a TSPS operator is added to the inward trunk through the TSPS or RTA switching network. After the appropriate actions are performed by the operator, the toll office incoming trunk circuit associated with the inward trunk is switched by the toll office to the appropriate toll switching trunk, thereby extending the inward call to the desired end office. The inward trunk remains in the connection between the calling and called customers after the operator has released from the connection.

1.7 New equipment

Several new pieces of transmission-related equipment were introduced as a consequence of RTA and PSS No. 2.

A new unified operator's telephone circuit, or UTC, was designed to provide several improvements such as dual headset operation and supervisor conferencing without transmission degradation. The UTC also provides a voice-switched attenuator (VSA) to control operator talker echo return, an automatic gain control (AGC) circuit to protect the operator from high-level signals, and independent sidetone adjustment to permit meeting sidetone level objectives. Gain and line equalization adjustments are supplied to permit the UTC to properly terminate any standard transmission facility.

To eliminate unwanted echo at the point where BR or operator position trunks are bridged onto a TCT, a new precision-balanced hybrid, the type 1P 4-wire terminating set was introduced. This hybrid is characterized by a high-impedance 2-wire port (approximately 11,600 ohms) and a very high trans-hybrid loss.

Two new 3-way, 4-wire bridging repeaters were also introduced to substantially improve transmission quality when bridging 4-wire circuits. The previous bridging arrangements produced a volume contrast to both the customers and the operator between calls on 2-wire and calls on 4-wire TCTs, with the 4-wire circuits exhibiting approximately 3 to 6.5 dB greater loss, depending on the direction of transmission. The new bridges eliminate this problem and permit gain adjustment in every direction from the bridging point.

1.8 Signaling considerations

Like the base TSPS, the RTA is required to transmit and receive various types of signals. Among these are address signals (i.e., the called and calling numbers), coin control signals, ringback signals, and ringforward signals. The RTA trunk circuits allow each signal to be transmitted in at least two different ways. Unlike the base unit trunks, however, the RTA trunks are not required to generate ±130 V dc signals for coin control and ringback.

The RTA must be able to receive address signals either as dial pulses or multifrequency (MF) tones from originating local offices but is required to forward address information to the toll office only in MF form. Coin control and ringback signals toward the originating office can be either inband (MF tones) or multiple wink (MW), which consists of a specified number of timed on-hook/off-hook dc "winks." Ringforward signals may be either +130 V simplex or a single "wink."

In TSPS/RTA, as in other systems not equipped with common channel interoffice signaling (CCIS), the signals described above must be transmitted over virtually the same paths used for voice transmission. These paths include the BR trunks between the base and the RTA since all the common signaling circuits (e.g., MF receivers, MF outpulsers, coin control and ringback circuits) are located at the base. Hence, care must be exercised when engineering the transmission paths to ensure

that signaling is properly considered. Transmission level points (TLPS) must be carefully controlled to guarantee correct processing of MF signals by the various switching offices involved. MF signaling specifications call for −7dBm per tone signal power at 0- TLP (i.e., −7dBm0). Changes are being incorporated into TSPS to comply with this specification.

II. OBJECTIVES AND GENERAL CONSIDERATIONS

2.1 Voice transmission objectives

A standard TSPS/RTA connection is a 3-party call among the calling customer, the called customer, and the TSPS operator (see Fig. 3). This standard connection was considered to be the same as three 2-way connections, each of which must meet its own transmission objectives.

The transmission objective set for the 2-way customer-to-customer connection is to provide loss-noise-echo performance, which is the same as that of regular direct distance dialed (DDD) toll calls that do not have TSPS access but have the same length. This objective applies whether or not the operator is in the connection and has two corollaries, namely: (*i*) the toll connecting trunk (TCT) satisfies the standard DDD network transmission requirements in both the 2-way and 3-way connection, and (*ii*) the performance provided on calls handled by TSPS is the same as calls handled by the DDD network.

The transmission objective placed on the 2-way operator-to-calling-customer connection was that it have loss-noise-echo performance equivalent to that provided on an average short DDD toll call between 100 and 150 miles in length. This objective is satisfied by the TSPS/RTA transmission design even when there are several hundred miles between the operator position and the TSPS access point on the incoming trunks to the toll office. This performance is obtained because (*i*) the TSPS access point was given the same transmission level as the toll office incoming trunk which reduces the level contrast at the operator position between the received volume from the calling customer and that from the called customer, (*ii*) the BR trunk has zero loss to minimize volume contrast observed by the operator between calls accessed at the base unit and those accessed at an RTA, (*iii*) circuit noise on the trunk facilities was limited, and (*iv*) impedance balance was provided for all trunks to avoid echoes.

Similarly, the transmission objective for the 2-way operator-to-called customer connection was that its loss-noise-echo performance be approximately the same as that of the connection between calling customer and called customer. Two potential transmission degradations that had to be considered in meeting this objective were (*i*) customer and operator talker echoes as a result of the extra 2-wire switching

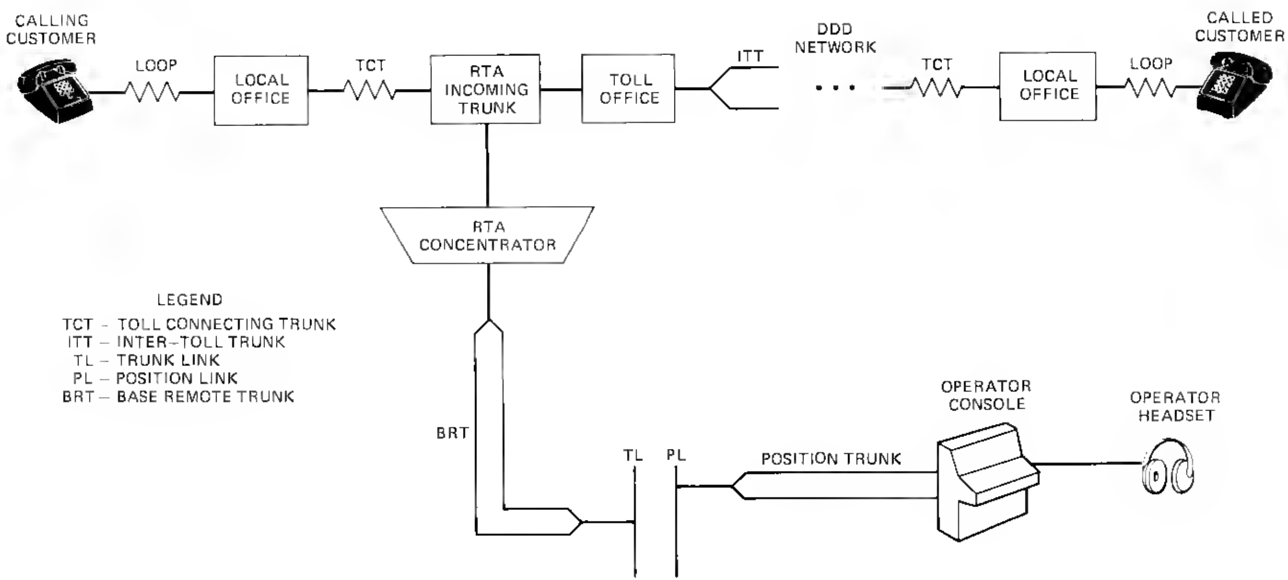

Fig. 3—Connection model of a typical call handled through TSPS via RTA.

point at the RTA and the long BR and operator position trunks, and (*ii*) high noise levels in long BR and operator trunk facilities.

Transmission objectives were also imposed on operator sidetone and trunk facility noise. The operator sidetone objective was made the same as that used for subscribers, namely, an acoustical sidetone path loss of 12 ± 4 dB. Noise objectives on all TSPS associated trunks were made the same as those for the DDD network trunks which use intertoll grade carrier facilities.

2.2 Deviations from requirements

Deviations from transmission requirements were constrained because the sum of many small deviations would cause large overall loss variations between connections. Some loss considerations were:

(*i*) Zero loss was required between the toll office and the base unit or RTA access points on toll connecting and inward trunks. Because any variation in this loss changes the effective TSPS access point on these trunks and, consequently, increases the speech volume from one customer and decreases it from the other, a permissible maximum variation of only 0.5 dB was set. For 2-wire trunks and 2-wire toll switches, the 0 to 0.5 dB loss requirement limits the wiring gauge and length that is used between the base unit (or RTA) and its associated toll office. Four-wire access trunks were aligned to 0 dB loss without difficulty. The permissible loss variation also determined the schedule for trunk maintenance and trunk down limits.

(*ii*) BR trunk loss variations were stipulated to limit the volume contrast for calls between operator and customers. The permitted variation was made the same as that for intertoll trunks in the DDD network. It was recognized that these level changes also affect signaling tones since MF outpulsers are only provided at the base unit so that the MF signaling tones are transmitted to the RTA over the BR trunks.

(*iii*) Loss variations in operator position trunks add to the volume contrasts heard by the customers. Such trunks were given same standard loss variations as intertoll message trunks.

2.3 Transmission level points (TLP)

TSPS conforms to the standard transmission level point (TLP) plan of the Bell System, which makes the local class 5 office a 0 TLP for outgoing signals. Since the trunk loss and its control are primary requirement in TSPS, transmission level points were adjusted as required to meet (*i*) trunk loss requirements, (*ii*) loading objectives for carrier facilities, and (*iii*) standardized toll office transmission level points. To do this, the outgoing TLP of the TSPS was adjusted to conform with the expected received level on the toll-connecting trunk being tested. All trunks internal to the base unit and RTA are considered to be at −3 TLP.

III. VOICE TRANSMISSION CONSIDERATIONS

As discussed in Section I, TSPS Generic 7 introduced the PSS No. 2, the RTA, and inward call-handling features. As a consequence, the RTA concentrator, which is a new switch, and new types of trunks (i.e., PSS No. 2 operator position, BR, and inward trunks) were added to existing TSPS base units as shown in Fig. 2. Modifications were also made in certain existing base unit circuits to meet the TSPS voice transmission objectives discussed in Section II. Each type of trunk associated with a base unit equipped with the RTA, PSS No. 2, and inward call-handling features was designed to satisfy specific transmission requirements to meet transmission objectives. These objectives were stated in terms of loss-noise-echo performance provided to the customer(s) and to the operator on all the possible connections used in TSPS. The loss-noise performance provided on a given type of connection was controlled by setting requirements on (*i*) the inserted connection loss (ICL) and (*ii*) the noise which may be introduced by each of the various trunks in the connections. The talker echo performance provided on a given connection depends upon both the loss and the round-trip signal propagation delay of the talker echo signal path. Because the round trip propagation delay of the echo path depends markedly on the length of a given connection, the loss in the echo path is used to control the echo performance provided on a given connection. For example, in the UTC described in Section 1.7, the loss of the echo path is controlled by introducing additional loss in the receive path when the talker speaks but not in the talker's transmission path. In addition, specific balance requirements are satisfied at all junctions between 4-wire and 2-wire transmission facilities. These specific transmission requirements (i.e., ICL, noise, and balance) are considered in subsequent sections.

Whenever the RTA feature is added to an existing TSPS base unit equipped with the original PSS No. 1 operator positions, the operator position trunks are modified as follows:

(*i*) The existing operator telephone circuits are replaced by the UTC with the voice-switched-attenuator (VSA) and automatic gain control (AGC) features enabled.

(*ii*) For operator positions located remotely from the base units, the DIC channel units at the base unit end of the trunk are replaced by a new DIC channel unit which incorporates the equivalent of a 1P 4-Wire Terminating Set (4WTS).

(*iii*) For operator positions located near the base unit, the 1H 4WTS used in the 24V4 repeater at the base unit end of the trunk are replaced by the 1P 4WTS.

Whenever the RTA feature is added, the service observing circuit used in existing TSPS base units is replaced by an improved circuit.

Prior to the introduction of Generic 7, a 3-way connection among (*i*) the TSPS operator, (*ii*) a service assistance operator, and (*iii*) the customer was permitted. However, with the introduction of Generic 7, such a 3-way connection is no longer provided because of transmission loss and balance problems with the extended range TSPS system. Only a 2-way connection is provided between a TSPS operator and a service assistance operator, during which the calling customer will be put on hold. The circuit modifications outlined above were needed to meet the echo performance objectives discussed in Section 2.1.

3.1 Network arrangements

Figure 2 is a functional block diagram of the voice transmission configuration of the base unit, operator positions, and RTA, and includes the various types of trunks. Typical trunking and switching arrangements at a base unit equipped with the inward call handling, a PSS No. 2, and an RTA are shown in Fig. 4. Figure 5 illustrates the typical trunking and switching arrangements for an RTA installation.

As shown in Fig. 4, the operator position trunks of the PSS No. 2 and PSS No. 1 retrofitted with the UTC as well as the service observing trunks all have 2-wire appearances on the position link circuit of the base unit switching network. These trunks use 4-wire facilities which are converted from 4-wire to 2-wire by a bridging hybrid (i.e., a 1P 4WTS, or equivalent) at the base unit. All the types of trunks shown in Fig. 4 that have appearances on the trunk link circuit of the switching network can be connected to at least one of the three types of trunks having appearances on the position link circuit. All BR trunks use 4-wire facilities while operator service trunks and centralized automatic message accounting (CAMA) transfer trunks may use either 2-wire or 4-wire facilities. When 4-wire facilities are used, a 900-ohm 4WTS (e.g., 1M 4WTS) is used to provide the necessary conversion from 4-wire to 2-wire. All inward trunks, 4-wire TCT, delayed call trunks, and service observing trunks use 4-wire facilities with bridging access to these trunks provided by 3-way, 4-wire bridging repeaters. The equivalent of a 900-ohm 4WTS is incorporated in the bridging repeaters to provide the necessary conversion from 4 wire to 2 wire. Two-wire TCTs are bridged directly at both the RTA and base unit. This is illustrated schematically in Figs. 4 and 5.

As shown in Fig. 5, all connections through the RTA concentrator between a BR trunk and either a TCT or an inward trunk are made on a 2-wire basis. All BR trunks at the RTA use 4-wire facilities and a 1P 4WTS to provide the necessary conversion from 4-wire to 2-wire transmission. The TCT and inward trunk arrangements are essentially the same as that described above for the base unit.

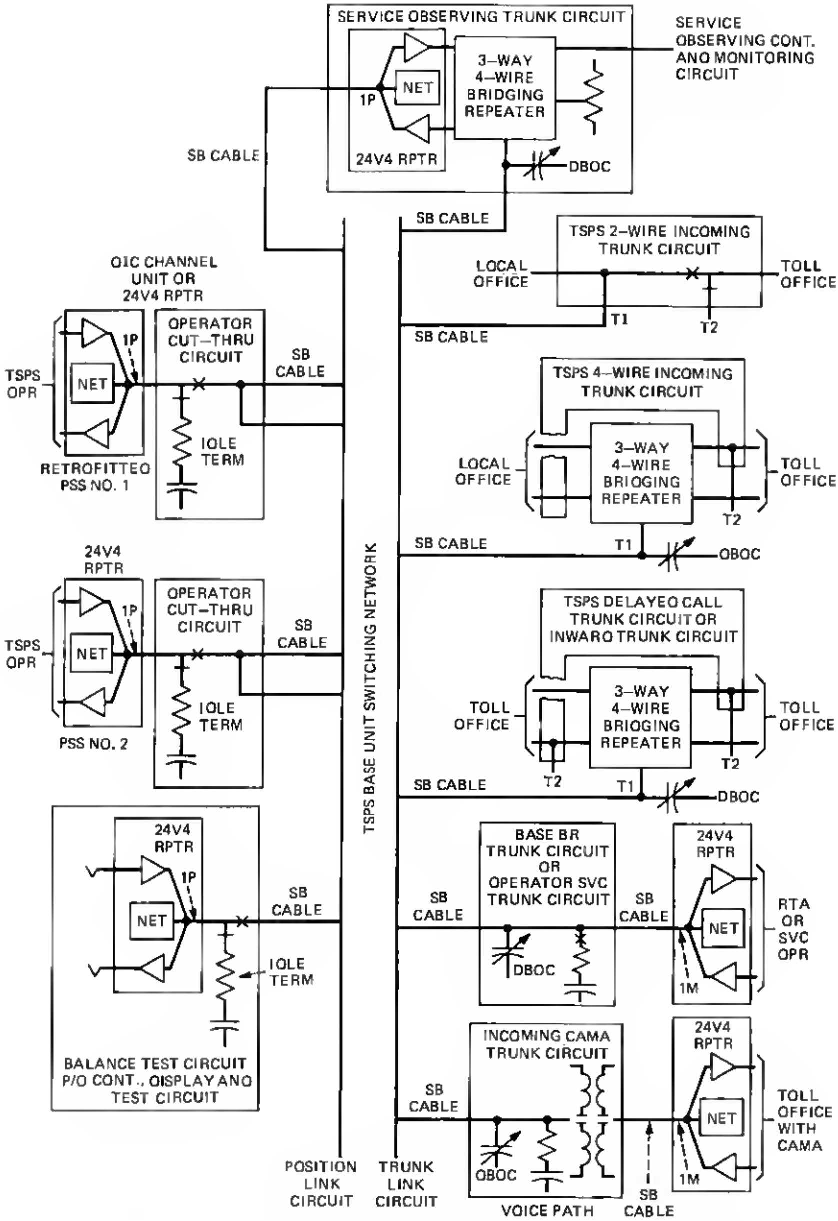

Fig. 4—TSPS base unit trunks and switching arrangements. To simplify the sketch, the T2 port connection to the trunk link circuit of the TSPS base unit switching network is not shown.

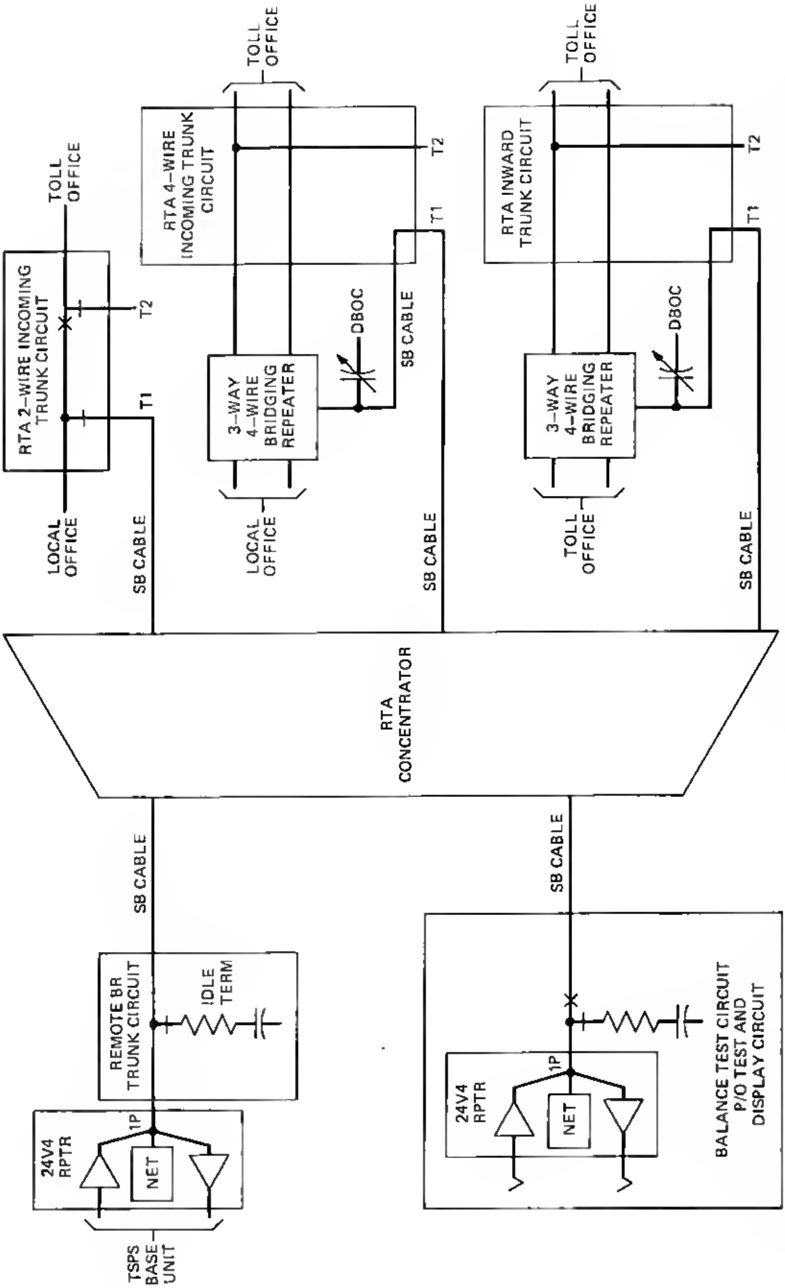

Fig. 5—RTA trunks and switching arrangements. To simplify the sketch, the T2 port connection to the RTA concentrator is not shown.

3.2 Inserted connection loss (ICL)

The ICL requirements on each of the various types of TSPS trunks shown in Fig. 2 are summarized in Table I. It should be noted that the introduction of Generic 7 has not affected the ICL requirements on those trunks which existed before its introduction. The ICL requirements on the new trunks introduced with Generic 7 are discussed next.

The ICL requirements must be the same for TCTs accessed by either a base unit or an RTA as for TCTs not accessed by TSPS to avoid any contrast in transmission performance provided to the customers between directly dialed calls and operator-assisted calls. One additional ICL requirement peculiar to TCTs provided with either base unit or RTA access is that the portion of the TCT between the TSPS bridging point and the outgoing side of the toll office switch should nominally be 0 dB with a maximum of 0.5 dB. This ICL requirement applies for both voice signals and MF signals and is needed (*i*) to equalize the transmission loss between the TSPS operator and the calling customer and between the operator and the called customer to minimize received speech volume contrast and (*ii*) to provide MF address signals to the toll office at the standard signaling power levels.

The ICL for the BR trunks is 0 dB. Since any TSPS operator can be called upon to service calls switched through either the base unit or an RTA, this requirement assures that there will be no significant volume contrast between such calls. It also ensures that the voice frequency MF signals generated at the base unit will reach the TCT bridging point at the standard power level.

The inward trunks introduced with Generic 7 may be considered as two secondary intertoll trunks in tandem, that is: (*i*) a secondary intertoll trunk from the toll office incoming to the base unit (or RTA)

Table I—Inserted connection loss requirements for TSPS trunks

Type of Trunk	ICL (dB)
1. Toll connecting trunk between TSPS No. 1 incoming trunk circuit at the TSPS base unit or RTA and the toll office	0, max. 0.5
2. PSS No. 2 operator position trunk	
a. Operator transmit direction	7
b. Operator receive direction	9
3. Retrofitted PSS No. 1 operator position trunk	
a. Operator transmit direction	7
b. Operator receive direction	9
4. Base-remote trunk	0
5. Inward trunk between TSPS No. 1 inward trunk circuit at the TSPS base unit or RTA and the toll office	0, max. 0.5
6. Delayed call trunk between TSPS No. 1 delayed call trunk circuit and toll office	0, max. 0.5
7. CAMA transfer trunk	
a. Voice path	0, max. 0.5
b. MF signaling path	0, max. 0.5
8. Operator service trunk	0, max. 0.5
9. Service observing trunk	0

for connection to an operator, and (*ii*) a secondary intertoll trunk from the base unit (or RTA) back to the toll office for connection to the desired end office. As such, each of these two sections of an inward trunk is composed of 4-wire facilities having an ICL of 0 dB nominal, with a maximum of 0.5 dB.

The ICL for the PSS No. 2 operator position trunks and for the retrofitted PSS No. 1 operator position trunks is the same. The ICL for both types of operator trunks depends on the direction of transmission. An ICL of 7 dB is used for the operator transmit direction so that the average speech power level from the TSPS operators delivered to the bridging point on the TCTs will be nominally equal to the average speech power level from the calling customers arriving at the same point. An ICL of 9 dB is used for the operator receive direction so that the preferred average speech power will be delivered to the operator when a customer's average speech level is applied to the bridging point on a TCT.

3.3 Noise

The maximum circuit noise permitted on all the various types of TSPS trunks existing before the introduction of Generic 7 was the same as on corresponding type trunks in the message network. This made it possible to use standard toll grade carrier arrangements in the makeup of the facilities for TSPS trunks whenever necessary. The noise limits on those trunks remain unchanged by the introduction of Generic 7 features, with the possible exception of the CAMA transfer trunks, which are discussed later. However, some special noise requirements for the inward, BR, and PSS No. 2 operator position trunks are introduced with Generic 7.

In the event that an inward call is extended to the desired called customer, the inward trunk remains in the overall connection between the calling and called customers after the operator releases from the connection. As discussed in Section 3.2, an inward trunk may be considered as two secondary intertoll trunks in tandem interconnected via a 3-way, 4-wire bridging repeater. To limit any degradation in the quality of the loss-noise performance provided to the calling and called customers, each of the two portions of the inward trunk are composed of low-noise 4-wire facilities such as intertoll grade T-carrier and/or 4-wire metallic facilities.

Any type or combination of types of intertoll grade voice facilities may be used in the makeup of a PSS No. 2 operator position trunks or BR trunks. The amount of noise introduced by the facilities is limited for loss-noise performance reasons. The loss-noise performance provided on customer/operator connections is adversely affected by the additional circuit noise introduced by long PSS No. 2 operator position trunks and long BR trunks.

If a PSS No. 2 is provided at a given TSPS base unit, but not an RTA, the loss-noise performance objective is met on customer/operator connections if the facility route length of analog carrier facilities used in any operator position trunk is no greater than 400 miles. This length limitation applies if the following noise maintenance limits are observed on the analog carrier facilities used in the operator position trunk:

Analog Carrier Length (route miles)	Remove From Service Limit (dBrnC0)	Maintenance Req'd Limit (dBrnC0)
0– 50	40	32
51–100	40	33
101–200	40	35
>200	44	37

If companded L-multiplex analog carrier facilities are used in the operator position trunk, the maximum facility route length may be extended to 1000 miles. It should be noted that the length of a single intertoll grade digital carrier facility (e.g., T-carrier) when used in tandem with an analog carrier facility can be ignored when applying these length restrictions. If the RTA feature is provided but not the PSS No. 2 feature, the above discussion on the makeup of PSS No. 2 operator position trunk facilities applies directly to BR trunks. If both the PSS No. 2 and RTA features are provided at a given TSPS base unit, the analog carrier facility length restrictions indicated above must be apportioned between the operator position trunks and the BR trunks. The length restrictions, of course, apply to all the diverse routes taken by the BR and operator trunks.

The introduction of RTA increases the likelihood that some of the CAMA transfer trunks to a given base unit will be long. The CAMA traffic, formerly handled by operators located near a toll office which is now being served by an RTA, will now most likely be routed over CAMA transfer trunks to the base unit for handling by TSPS operators. This, coupled with the possibility that the base unit may also be equipped with a remote PSS No. 2, places more stringent noise requirements on the CAMA transfer trunks so that their maximum circuit noise is now the same as for the BR trunks discussed above.

3.4 Transmission balance

RTA and PSS No. 2 add a new 2-wire switching point (RTA concentrator) and long lengths of facilities to the overall connection between the customers and the TSPS operator. As discussed in Section 1.5, the extra switching point introduced another potential source of talker echo whenever the trunks to be switched use 4-wire facilities. The long lengths of facilities increase the round-trip propagation delay of any

talker echo signal already existing which makes that echo more disturbing to the talker. To meet echo performance objectives on connections involving TSPS operators, balance requirements must now be placed on the various connections through the base unit and/or through the RTA when at least one of the trunks involved in the connection uses 4-wire facilities. Balance refers to matching circuit impedances to control the magnitude of the signal reflected toward the source at the junction between 4-wire and 2-wire facilities.

In general, the termination of a 4-wire facility and its conversion to a 2-wire facility is accomplished with a 4WTS, or equivalent. A 4WTS contains a balanced hybrid transformer that facilitates the transfer of signal power from the 4-wire receive path into the 2-wire facility and from the 2-wire facility into the 4-wire transmit path. However, some signal power arriving on the 4-wire receive path will be returned on the 4-wire transmit path whenever differences exist between the impedance of the 2-wire facility and the impedance of the balancing network of the 4WTS. The degree of balance between these two impedances will determine what portion of the signal power will be returned to the source.

The balancing networks used in each of the various types of 4WTSs (or equivalent) shown in Fig. 4 and 5 consist of a compromise network plus an adjustable network build-out capacitor (NBOC), which shunts the compromise network. The compromise network is designed to provide impedances over the voice frequency band of 200 to 3400 Hz that match the nominal impedance of the 2-wire circuits which may be connected to that 4WTS. The NBOC is included in the balancing

Table II—Balance requirements on the bridging hybrid at the base unit end of PSS No. 2 and retrofitted PSS No. 1 operator position trunks and the RTA end of base-remote trunks

Type of Trunk Connected to TSPS Bridging Hybrid	Echo Return Loss (dB)		Singing Return Loss (dB)	
	Median	Minimum	Median	Minimum
1. Base unit and RTA				
a. 2-wire toll connecting trunk	15	13	N.S.*	6
b. 4-wire toll connecting trunk	N.S.	19	N.S.	15
c. Inward trunk	24	21	19	16
2. Base unit				
a. Base-remote trunk	24	21	19	16
b. 4-wire delayed call trunk	24	21	19	16
c. 4-wire operator service trunk	24	21	19	16
d. 4-wire CAMA transfer trunk (voice path)	N.S.	21	N.S.	16
e. Service observing trunk	24	21	19	16

* Not specified.

Table III—Balance requirements on 4WTS, or equivalent, associated with various types of 4-wire trunks on connections to a bridging hybrid in TSPS base unit or RTA

Type of 4-Wire Trunk	Echo Return Loss (dB) Median	Echo Return Loss (dB) Minimum	Singing Return Loss (dB) Median	Singing Return Loss (dB) Minimum
1. Base unit and RTA				
a. Toll connecting trunk	N.S.*	26	N.S.	19
b. Inward trunk	N.S.	26	N.S.	19
2. Base unit				
a. Base-remote trunk	N.S.	26	N.S.	19
b. Delayed call trunk	N.S.	26	N.S.	19
c. Operator service trunk	N.S.	26	N.S.	19
d. CAMA transfer trunk (voice path)	N.S.	26	N.S.	19
3. Service observing trunk	N.S.	26	N.S.	19

* Not specified.

network to simulate the capacitance of the office cabling included between the 2-wire port of the 4WTS and the point of good impedance of the connecting circuit, which is defined as a point of fixed nominal 2-wire impedance. For example, the point of good impedance of a trunk using 4-wire facilities is the 2-wire port of a 4WTS.

The balance requirements on the 1P 4WTS (or equivalent) at the base unit end of PSS No. 2 trunks, retrofitted PSS No. 1 trunks and service observing trunks, or at the RTA end of BR trunks, vary depending upon the type of trunk connected through the base unit network or RTA concentrator to the 1P 4WTS. The balance requirements, listed in Table II as a function of trunk type, are identical regardless of whether the connections are made through the base unit or through the RTA.

The balance requirements on the 4WTS (or equivalent) associated with the various types of 4-wire trunks which can be connected through the base unit or the RTA to a 1P 4WTS are summarized in Table III. Again, balance requirements are identical for a given type of trunk switched through either the base unit or an RTA.

The balance requirements listed in Tables II and III are given in terms of echo return loss (ERL) and singing return loss (SRL) as measured at the 4WTS (or equivalent) using a return loss measuring set (RLMS). An ERL measurement is a weighted average measurement of the return losses for each frequency in the echo frequency range. An SRL measurement is the lesser of two weighted average measurements of the return losses, one measurement covering the frequencies at the lower end of the voice frequency band and the second covering frequencies at the upper end of the voice frequency band.

No resistance build-out capability is provided in the balancing networks of the various 4WTS (or equivalent) used in TSPS applications.

Therefore, to meet specific balance requirements at any given 4WTS maximum allowable lengths of office cable (26-gauge switchboard cable in both base units and RTAs) between the points of good impedance of the trunks and their 2-wire appearance on the base unit switching network or RTA concentrator have been specified. Those segments of switchboard cable in which length must be controlled are labeled "SB CABLE" in Figs. 4 and 5.

In a given base unit or RTA, the value of the NBOC in the balancing networks of all the 1P 4WTSs will be set to some compromise value such that the balance requirements are met on connections through the switching network to all possible 2-wire TCTs. To meet balance requirements when the value of the NBOC is fixed, variation in the shunt capacitances of the switchboard cables shown in Figs. 4 and 5 must be controlled. If the switchboard cabling capacitance variation is sufficiently large, balance requirements will not be met on all possible connections if the value of the NBOC is to remain single-valued.

It should be noted that the shunt capacitance of the switchboard cabling between a 1P 4WTS and the point of good impedance of any of the various trunks using 4-wire facilities shown in Figs. 4 and 5 will, in general, be much smaller than the value of the NBOC in the hybrid balancing network of the 1P 4WTS required to meet balance requirements on connections to TCTs providing 2-wire bridging access. To reduce this cabling capacitance variation, bridged capacitance is added to the shorter 2-wire switchboard cabling paths to increase their effective shunt capacitance and make them equal that of the longer 2-wire cabling paths. This is accomplished by adding a drop build-out capacitor (DBOC) in the shorter 2-wire cabling paths as indicated in Figs. 4 and 5. In some cases, the DBOC is supplied as part of the TSPS or RTA trunk circuit or as part of the 4-wire bridging repeater. In other cases, a separate DBOC is supplied and wired on a bridged basis across the 2-wire switchboard cabling path between the point of good impedance of a given trunk and its appearance on the base unit switching network or on the RTA concentrator.

Terminal balance requirements are imposed on connections in a toll office from any intertoll trunk to any TCT. When the TCT provides TSPS bridging access, the same terminal balance requirements apply. The current toll office terminal balance requirements listed in Table IV are for the most part independent of the type of toll office involved, but are dependent upon the general makeup of the TCT facilities. To meet terminal balance requirements on 2-wire TCTs providing TSPS bridging access, the maximum length and the gauge of the switchboard cabling used to interconnect the base unit or RTA incoming trunk circuit, the toll office, and the point of good impedance of the TCT facilities (e.g., 4-wire terminating set, impedance compensation network) must be controlled as a function of (*i*) the type of toll office, (*ii*) the length and

Table IV—Toll office balance requirements

1. Terminal balance
   a. 2-wire facilities with 2-dB pad (intrabuilding):
      ERL: 22 dB* median, 18 dB minimum
      SRL: 14 dB median, 10 dB minimum
   b. 2-wire facilities or 4-wire facilities with 2-wire extensions (interbuilding):
      ERL: 18 dB median, 13 dB minimum
      SRL: 10 dB median, 6 dB minimum
   c. 4-wire facilities:
      ERL: 22 dB median, 16 dB minimum
      SRL: 15 dB median, 11 dB minimum
2. Through balance
      ERL: 27 dB median, 21 dB minimum
      SRL: 20 dB median, 14 dB minimum

* 20 dB for No. 5 crossbar toll offices only when TCT provides TSPS 2-wire bridging access.

gauge of switchboard cabling internal to a 2-wire toll office, and (*iii*) the value of the NBOC of the balancing network of the intertoll hybrids in a 2-wire toll office.

The terminal balance requirements listed in Table IV also apply to connections through the toll office from any CAMA transfer trunk, TSPS inward trunk, or TSPS delayed call trunk to any TCT. The toll-office through balance requirements also listed in Table IV must be met on connections through the toll office between any TSPS inward or delayed call trunk and any intertoll trunk. These balance requirements have been imposed to limit any degradation in the quality of the echo performance provided on the overall connection resulting from the introduction of additional 2-wire switching points in the overall connection between customers. To limit degradation of the echo performance provided on the overall connection between two customers resulting from the increased round-trip propagation delay of the echo path caused by adding either a TSPS inward or a delayed call trunk in tandem with the overall connection, the maximum route length of the facilities composing each of the two portions of an inward or delayed call trunk must not exceed:

(*i*)	Metallic facilities	9 miles
(*ii*)	T-carrier facilities	50 miles
(*iii*)	T-carrier with metallic extensions	Determined by the requirement that the length of the T-carrier facilities plus 10 times the length of the metallic extension must not exceed 50 miles.

IV. ADDRESS SIGNALING AND SPECIAL SIGNALING

4.1 Signaling methods

RTA trunks utilize classical loop and E&M supervisory signaling methods. Nonsupervisory signal handling, however, is different.

Signaling between the RTA and the local or toll switching offices typically assumes one of two forms: (*i*) ac multifrequency tone bursts and (*ii*) dc pulses or "winks." When MF tones are used, the signaling is usually between the local or toll offices and the base unit with the RTA essentially transparent. This is the case for MF address signals, automatic calling number identification (ANI), and inband coin control and ringback. When dc pulsing is employed, however, signaling is restricted to the relatively short trunks between the RTA and the local and toll offices. This is the case for dc dial pulses and multiple wink (MW) coin control, ringback, and ringforward.

The RTA does not provide ±130 V dc signaling for coin control, but does provide +130 V dc simplex signaling for ringforward toward the toll office.

4.2 Dial pulse receiving

It would be nearly impossible for dc dial pulses (DP) generated at an originating office to pass through the RTA and over the extremely long BR trunks that could be encountered and still be reliably detected by a digit receiver at the base unit. An alternative way of handling DP at the RTA is required. Rather than being transmitted to the base, dial pulses received at an RTA are blocked in the trunk circuit where they are counted and encoded by the Position and Trunk Scanner (PTS) circuit in the PCL. The value of each dialed digit is then transmitted in the interdigital interval to the SPC over the PCL data links and not over the normal voice transmission facilities.

When all the called digits have been obtained, the SPC must determine if the originating office is equipped with ANI (automatic number identification). If it is, an MF receiver must be connected to the T1 port of the RTA incoming trunk via the base networks, a BR trunk, and the RTA concentrator. The trunk circuit is then directed to send an off-hook "wink" to the originating office requesting transmittal of the calling number. The MF tones then follow essentially the same path used to connect an operator to the calling customer. Hence, in the design of the toll-connecting and BR trunks, consideration must also be given to signaling.

4.3 Multifrequency receiving

If the RTA incoming trunk is identified as having MF rather than dial pulse signaling, the SPC establishes a transmission path to a base unit MF receiver in much the same manner as described above to receive the ANI digits after dial pulsing. Once a transmission path is established, the RTA is directed to signal the originating office via a 200-ms off-hook wink to start MF pulsing. After all the called number digits have been registered, the SPC must determine if the originating office

is equipped for ANI and, if so, must signal the office to forward the calling number. This is done by directing the RTA trunk to go off-hook. Thus, in the case of MF originating traffic, the signaling and the voice transmission paths are identical.

4.4 Multifrequency outpulsing

Once the called number has been registered by the SPC, it must be forwarded or outpulsed to the toll office to effect call completion. Since this is normally done at the same time that an operator is connected to the calling customer (acknowledging coin deposits, getting special billing information, etc.), a second transmission path must be established, this time via the T2 port of the incoming trunk circuit. In the case of an RTA call, the MF outpulser circuit is connected to the trunk via a BR trunk and the RTA concentrator.

MF signals transmitted from TSPS to the toll office, therefore, follow a somewhat different route than voice signals, traveling via the T2 port of the trunk circuit while voice signals use only the T1 port. In the case of the relatively simple 2-wire trunk circuits, this makes little difference (see Fig. 6). In the case of 4-wire trunk circuits, however, the MF signals do not go through and therefore do not receive the benefit of the amplifiers in the associated bridging repeaters

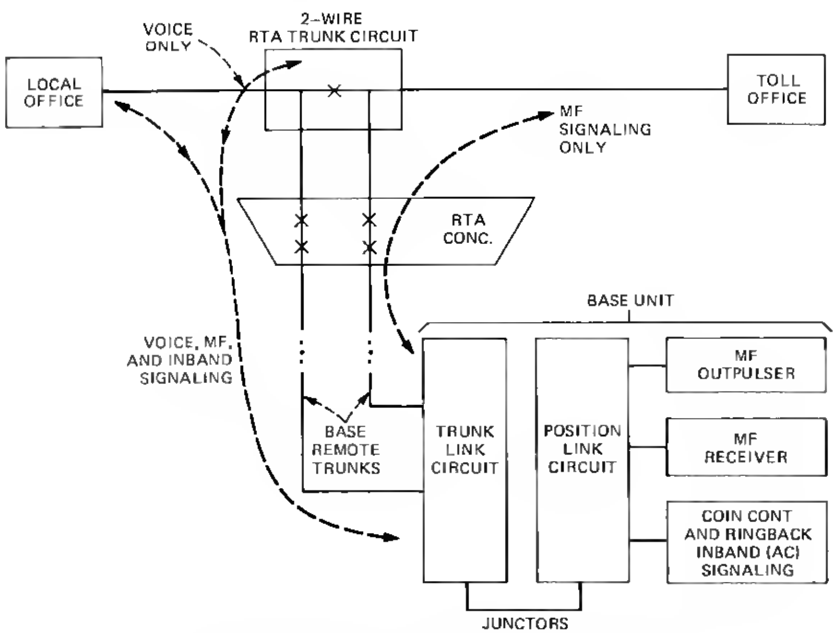

Fig. 6—MF signaling in 2-wire RTA trunk circuits.

(see Fig. 7). Thus, the 4-wire circuits require additional amplifiers to ensure that the proper ratio of MF to voice is transmitted to the toll office.

Care must also be exercised during the design of the trunk circuits and facilities to ensure that they are properly terminated at all times, particularly at the 2-wire/4-wire junctions. Improper termination of the new 1P 4-wire terminating set can lead to unintentional circuit gains or losses with resulting MF signaling difficulties.

For typical DDD calls, the TSPS must transmit the MF signals only as far as the serving toll office which, even for RTA and its toll office, is by design over trunk facilities of no more than 0.5-dB loss. With the introduction of International Direct Distance Dialing (IDDD) in Generic 5, however, TSPS must transmit MF signals to international "gateway" offices which may be more than 2000 miles away. On such calls, TSPS must first transmit a preliminary set of digits to the toll

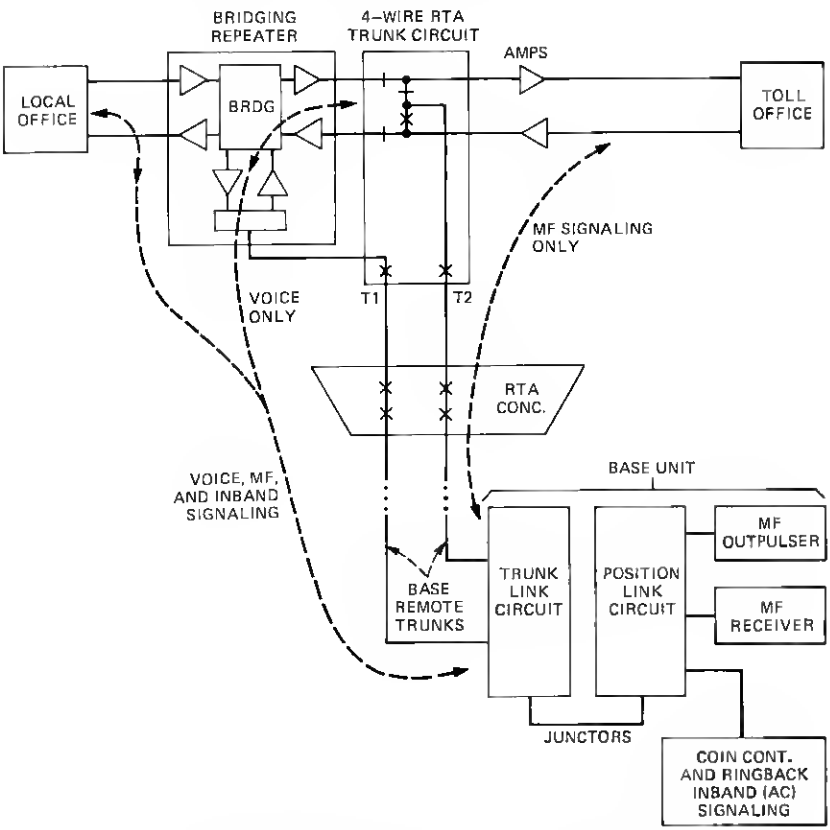

Fig. 7—MF signaling in 4-wire RTA trunk circuits.

office which will cause a connection to the gateway office to be established. Upon receipt of a signal from the gateway office, TSPS must then MF-outpulse the called number.

Transmission facilities of this length may be made up of many segments, be characterized by up to 10 dB of loss, and/or be equipped with echo suppressors. Hence, the MF signals must be transmitted from TSPS at the current standard level of −7 dBm0 per frequency to insure they are not too strong and cause facility overload, clipping, or unacceptably high crosstalk and are not too weak to be successfully received by the gateway offices.

4.5 Coin control and ringback

The RTA trunks are all equipped to provide coin control and ringback by transmitting either inband (ac) or multiple wink (dc) signals. Inband signaling requires the use of the coin control and ringback (CCR) circuit at the base unit to supply the inband frequencies. The SPC establishes a connection between the CCR and the T1 port of the RTA trunk via the base network, a BR trunk, and the RTA concentrator. The RTA trunk is then directed to transmit an alerting on-hook wink toward the local office followed by a quiet interval of 100 ms. Inband frequencies for coin collect (700/1100 Hz), coin return (1100/1700 Hz), or ringback (700/1700 Hz) are then generated by the CCR circuit.

For multiple wink signaling, the RTA trunk circuits are each equipped with an integrated circuit which when properly addressed by the PCL signal distributor circuit, will generate three winks for coin collect, four winks for coin return, or five winks for ringback. One wink and two winks, not currently used in the multiple wink signaling arrangements, are available for future use. The multiwink generator, however, does generate the one wink as an alerting signal for inband signaling and for ringforward (see Section 4.6).

Timing for the multiwink generator is derived from the 12.346-ms Position and Trunk Scanner clock in combination with an integrated circuit decade counter in each trunk circuit. Hence, the winks appear as squared waves with symmetrical 123-ms intervals.

4.6 Ringforward

The RTA trunk circuits can be arranged on an optional basis to provide either wink or simplex versions of the ringforward signal. Timing for this signal is produced by the same MW generator in the trunk circuits used for coin control and ringback. If the +130-V dc supply is connected to the trunk circuit (optional), the ringforward signal will be +130-V simplexed onto the T and R leads toward the toll office. Otherwise, the T and R leads are simply opened and a wink-type signal is sent to the toll office.

V. MAINTENANCE FACILITIES

5.1 CDT modifications

The control, display and test (CDT) frame at the base unit serves as the trunk test panel and also as the primary status display for the TSPS peripherals and subsystems. With the introduction of RTA and PSS No. 2, it was necessary to modify the CDT to accommodate BR trunk and PSS No. 2 position trunk testing and to add a status display for the PCL circuits and data links. A single display is provided which, under control of the SPC, can show the status of any one of the 15 PCLs possible in a given TSPS. This novel display is shown in Fig. 8.

To meet long-range Bell System objectives on test-tone power levels and to prevent crosstalk and other disruptions of carrier systems which are likely to be used for the long BR and operator position trunks, the CDT was modified to permit trunk testing at power levels 10 dB below TLP. Since the base unit, the RTA, and all trunks internal to TSPS (e.g., BR trunks) are considered to be at −3 TLP, the test tones utilized will be at −13 dBm. Coincident with this change, a system for varying the test pad (TP) values was introduced to achieve consistent values of expected measured loss (EML) when testing the difference segments of a TCT. This multilevel testing scheme is discussed later.

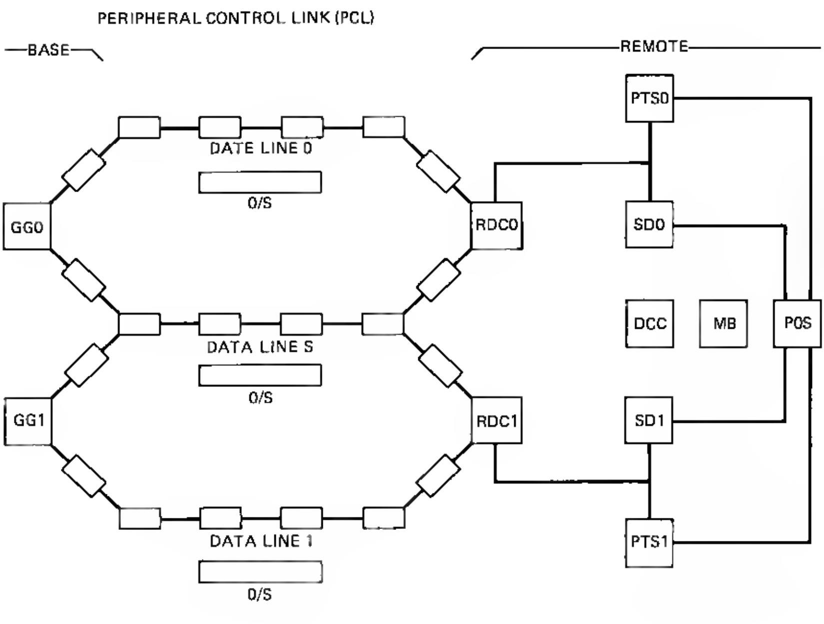

Fig. 8—Control display and test circuit frame—PCL equipment status display.

5.2 Test and display circuit

The test and display circuit (TDC), located at remote RTA and PSS No. 2 sites, provides functions similar to those of the CDT at the base unit. The TDC provides a PCL display, trunk group status indicators, carrier facility and carrier transfer circuit status lamps, and other major circuit status lamps.

A major feature of the TDC is its transmission and noise measuring circuit which is similar to the Automatic Transmission Measuring System 52A Responder. This circuit takes a "snapshot" measurement of the test tone or noise level on a trunk under test and displays the results on an LED digital display. The measured results are also passed in BCD form to the scanner circuit for transmission via the PCL to the base unit. Since the RTA and PSS No. 2 sites are likely to be unattended, this arrangement facilitates one-person testing of BR and position trunks.

On request from the CDT, the TDC is placed in a remote control mode, responding to commands from the SPC transmitted via the PCL. In this mode, the following tests can be made either semiautomatically or by automatic progression from one test to the next and for each trunk in the trunk group:

(i) Near-to-far end loss: Measurement is made by the TDC, transmitted to the base, and printed on the maintenance center TTY.

(*ii*) Far-to-near end loss: Measurement is made on a transmission measuring set built into the CDT.

(*iii*) Near-to-far end noise: Measurement is made as in test (*i*).

(*iv*) Far-to-near end noise: Measurement is made on a 3B noise measuring set built into the CDT.

In its local mode, the TDC is used to test the segments of the TCTS between the RTA and the local offices and between the RTA and the toll office. It can also be used for 2-person testing of BR or operator position trunks. As with the CDT, tests on these circuits are made at 10 dB below TLP. Test jacks are provided at the TDC to facilitate the use of portable test equipment in testing the PCL data links, TCTS, BR trunks, and the teletypewriter data channel.

5.3 Dial access test lines

A new transmission maintenance facility introduced concurrently with Generic 7 is the Dial Access Test Line circuit or DATL. The DATL circuits, located at both the RTA and the base unit, provide the equivalent of a code-100 test line (quiet termination), a code-102 test line (milliwatt 1000-Hz tone) and a code-106 test line (loop-around). These circuits permit maintenance craft at the local and toll offices to reach a TSPS test termination by simply dialing a test code, typically

959-120X for the quiet termination or 959-122X for the milliwatt tone (the "X" signifies that the last digit is immaterial).

Each DATL has two ports, each of which can supply a quiet termination or milliwatt tone. When two trunks in the same trunk group access the DATL at the same time, the SPC will automatically loop the trunks to each other through the DATL. To prevent this arrangement from being used as an unauthorized "meet me" circuit, the DATL is equipped with 60A control units which are designed to pass signals within a very narrow passband centered at 1004 Hz. If energy outside this band and above approximately −30 dBm is detected, the 60A will open the loop. The loop-around path produces an EML twice that of a 1-way connection.

5.4 Maintenance improvements

The introduction of multilevel testing at the CDT and TDC frames constitutes a noteworthy transmission maintenance improvement. In this scheme, the values of the test pad is changed depending upon the direction of the tests, that is, toward the local office, toll office, base unit (for the TDC), or RTA (for the CDT). Testing a toll-connecting trunk associated with TSPS (including RTA) may also involve testing the TCT segments. There are three possible tests: local office to toll office, local office to TSPS, and toll office to TSPS. Note that each switching center can list a given trunk with two different terminating offices, yielding the likelihood of two different EMLs for the same circuit. Test-pad switching at the CDT and TDC eliminates that condition.

Consider a TCT with ICL of 3 dB being tested between a local office and a toll office equipped with a typical 2-dB test pad. The EML at both offices would be 5 dB. However, if the same TCT circuit is tested between TSPS and the toll office when the ICL of the TCT segment is 0 dB, the toll office would now measure 2 dB. To eliminate this inconsistency, 3-dB test pad is inserted at the CDT (or TDC) to make the toll office measurement 5 dB. Similarly, if the TCT segment between the local office and the TSPS is tested, the local office would now measure 3 dB (the ICL value) or possibly 6 dB if the CDT or TDC test pad is 3 dB, as above. Instead, the CDT (TDC) test pad is switched to 2 dB, making the measurement at the local office a consistent 5 dB.

Since the TSPS base unit can be associated with more than one toll office, the CDT is equipped with test pads of 0, 2, and 3 dB to simulate the test pads found in Bell System toll offices. The TDC may have only one toll test pad value, 0, 2, or 3 dB.

VI. CONCLUSION

The introduction of RTA and PSS No. 2 with their long BR and operator position trunks required establishment of a new comprehen-

sive transmission plan. Several existing base unit circuits had to be modified or completely redesigned to meet tightened transmission standards. Equipped with the new 3-way, 4-wire bridging repeaters, unified telephone circuits, and precision 1P 4-wire terminating sets, the RTA and PSS No. 2 provide generally equivalent, if not better, transmission quality to that which previously existed in TSPS.

VII. ACKNOWLEDGMENTS

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REFERENCES

1. T. F. Arnold and R. J. Jaeger, Jr., "TSPS/RTA—An Overview of the Remote Trunk Arrangement," ICC75 Conference Record, *III* (June 1975), pp. 46-1—46-4.
2. J. A. Hackett, K. A. Heller, and L. A. Rigazio, "TSPS/RTA—Reliability and Maintainability in the Hardware Design," ICC75 Conference Record, *III* (June 1975), pp. 46-5—46-10.
3. S. M. Bauman and M. F. Sikorsky, "TSPS/RTA—Call Processing," ICC75 Conference Record, *III* (June 1975), pp. 46-11—46-16.
4. W. L. Brune and R. J. Frank, "TSPS/RTA—Transmission Considerations," ICC75 Conference Record, *III* (June 1975), pp. 46-17—46-21.
5. V. L. Ransom and G. Espinosa, "TSPS/RTA—Application and Planning Information," ICC75 Conference Record, *III* (June 1975), pp. 46-22—46-25.
6. T. F. Arnold, "TSPS Goes to the Country," Bell Laboratories Record *55*, No. 6 (June 1977), pp. 147-153.
7. W. S. Hayward, Jr. and R. E. Staehler, "TSPS No. 1: An Overview," B.S.T.J., this issue pp. 1109-1118.
8. S. M. Bauman, R. S. DiPietro, and R. J. Jaeger, "TSPS No. 1: RTA Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1119-1135.
9. A. F. Bulfer, W. E. Gibbons, and J. A. Hackett, "TSPS No. 1: RTA Hardware and Software Implementation," B.S.T.J., this issue, pp. 1167-1205.